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HEAT DISSIPATION FOR HIGH POWER OPTICALLY PUMPED SEMICONDUCTOR VERTICAL EXTERNAL CAVITY SURFACE EMITTING LASERS

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This is an interim report on research on vertical external-cavity surface-emitting lasers, a collaboration between AFRL and the University of Arizona. This report investigates heat generation under high-power optical pumping for VECSELs, and studies the effects of sample mounting and substrate removal by means of photoluminescence experiments.

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Heat Dissipation for High Power Optically Pumped Semiconductor Vertical External Cavity Surface Emitting Lasers

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Abstract: We investigate heat generation under high power optical pumping for vertical external cavity surface emitting lasers. The effects of sample mounting and substrate removal on the photoluminescence are investigated. Efficient heat extraction is reported.

Optically pumped semiconductor (OPS) vertical external cavity surface emitting lasers (VECSEL) have a number of advantages over conventional semiconductor diode lasers, such as high brightness and good beam quality [1,2]. High power CW operation of the OPS-VECSEL requires proper thermal design of the structure and efficient heat extraction from the active region to avoid thermal lensing, decreased gain, and shut-off resulting with resonant frequency shifts. In order to achieve this goal, the epitaxial structure should be as close as possible to the heat sink. In addition, mechanical strain caused by the mounting method should be avoided. In this paper we investigate several methods for substrate removal and sample mounting.

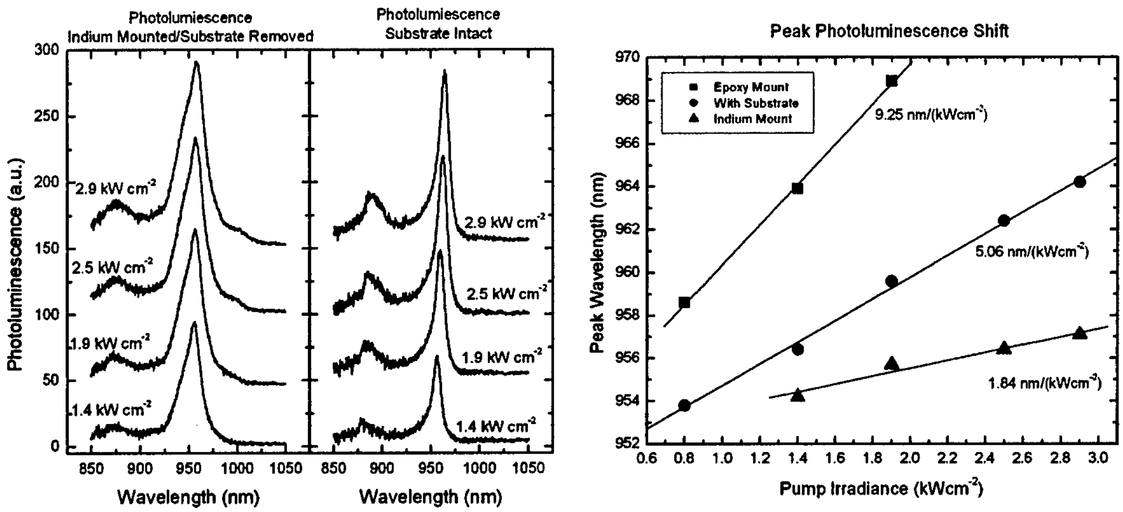
The epitaxial structure used consists of 14 strained $In_{0.15}Ga_{0.85}As$ 8nm quantum wells and 129.6 nm wide GaAs barriers. The barrier width is designed to position the quantum wells at the antinodes of the longitudinal standing wave of the VECSEL. For purposes of this test, there is no DBR mirror included in growth. There is an $Al_{0.8}Ga_{0.2}As$ etch-stop grown between the active structure and the substrate to facilitate chemical substrate removal.

The intra-cavity surface is left uncooled, while the heat is to be primarily removed through opposite face. We study three mounting methods: (1) leaving a nominally 650 μm substrate, (2) mounting the epitaxial side of the sample to an AlN submount using a thermal epoxy, completely remove the substrate from opposite side, and (3) the same procedure as method 2, but instead using indium to solder the semiconductor to the AlN submount.

For substrate removal, we first attach the semiconductor to the AlN submount from the epitaxial side. We then mechanically lap the GaAs substrate to a thickness of about 120 μm. The remaining GaAs substrate is subsequently removed by selective wet chemical etching using $C_6H_8O_7{:}H_2O_2$. A single λ/4 dielectric layer is then applied to the intra-cavity surface using e-beam evaporation. Samples with the entire substrate removed are only about 2 μm in total thickness.

In measurements, all samples are mounted, using thermal grease, to a water-cooled heat sink maintained at 10 °C. We optically excite the material with an 808 nm source incident at 45 degrees, and capture the photoluminescence (PL) in reflection mode from the wafer normal. Pump densities used are commensurate with typical above-threshold pump densities.

In this structure there is no layer compensating the quantum well strain. To investigate mismatch of the coefficient of thermal expansion (CTE) between the quantum wells and the submount, and strain generated by substrate removal, PL curves taken before and substrate removal are compared. Despite the elevated indium processing temperature, the PL line shape remains reasonably consistent before and after substrate removal, indicating no strain relaxation (see Fig. 1a).



a) b)

Fig. 1. a) PL result comparing indium solder mounted sample (left) and unprocessed sample (right). b) Peak PL measurement for different mounting methods.

Fig. 1b records the shift in PL as a function of pump irradiance. If the heat is to be removed through the entire substrate, this results in a peak wavelength shift rate of 5 nm/(kWcm^{-2}). Assuming a typical wavelength shift of 0.3 nm/°C, this results in a temperature rate of change of about 16 °C/(kWcm^{-2}), unacceptably high for efficient VECSEL operation

There are several advantages using thermal epoxy including low stress, low temperature application, and ease of process. We see however the thermal epoxy is not effective for heat removal (Fig. 1b), with a 31 °C/(kWcm^{-2}) temperature rate of change. This is due in part to the relatively low thermal conductivity of the epoxy (~7 W/m/K) relative to the substrate thermal conductivity. Minimum epoxy thickness is on the order of 20 μm, resulting in a significant thermal resistance.

The best results by far are obtained by mounting the sample using indium solder. While this is done at an elevated temperature, there is no additional stress applied to the semiconductor, as indicated by the PL shape (Fig. 1a). The indium solder mounted sample's PL shifts at only about 2 nm/(W cm^{-2}), which indicates a temperature rate of change of only 6 °C/(kWcm^{-2}. These results will be somewhat depreciated when the distributed Bragg reflector (DBR) stack is grown, as the heat is to be removed *through* the DBR layers.

In comparing mounting methods and processing techniques, we find that indium solder used in conjunction with substrate removal is effective for heat removal from VECSEL material. Future use of CVD diamond should improve heat transfer due to its superior thermal conductivity.

References

1. Mark Kuznetsov, Farhad Hakimi, Robert Sprague, and A. Mooradian, IEEE J. of Selected Topics in Quantum Electronics, Vol. 5, No. 3, 1999, pp. 561--573
2. S. Lutgen, T. Albrecht, P. Brick, W. Reill, J. Luft, and W. Spath, Applied Physics Letters, Vol. 82, No. 21, 2003, pp. 3620--3622